Electronic Version
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Claims

[c1] 1. An aerosol-particle analyzer (APA) for measuring the amount of an analyte in particles in a gas comprising:
(a) an analysis liquid chosen such that when the analysis liquid is mixed with the particles, an optical property of the analysis liquid varies according to the amount of the analyte in the particles;
(b) a charged droplet generator, having a charged-droplet generator output, that generates a charged droplet of the analysis liquid (CDAL) and ejects it out of said charged-droplet generator output when signaled to do so;
(c) a charger, enclosed in a gas-tight enclosure, having a gas input and charged particle output, arranged to:
(i) accept the gas and the particles therein through said gas input;
(ii) impart an electrical charge to any of said particles accepted, such that the now charged particles will have a charge opposite that of the CDAL; and
(iii)permit the gas containing the charged particles to exit through the charged particle output;
(d) a particle-droplet-collision subsystem (PDCS) consisting of an electrodynamic levitator enclosed in a gas-

tight container, having a charged-droplet input connected to the charged-droplet generator output, a charged particle input connected via gas-tight connection to the charged particle output, a PDCS CDAL output, and a vacuum connection that:

(i) accepts the CDAL via the charged-droplet input;

(ii) accepts the gas containing the charged particles via the charged particle input;

(iii) levitates the CDAL into a position where the gas containing the charged particles drawn from the charger flows past it so that the charged particles, collide with and combine with the CDAL in part because they are electrically attracted to the oppositely charged CDAL; and

(iv) ejects the CDAL that has combined with the charged particles, in a desired direction via the PDCS CDAL output;

(e) a vacuum pump connected to the PDCS vacuum connection that draws the gas and particles into the charger gas input and through the charger and then on into the PDCS, where the gas and any particles not combined with the CDAL are then evacuated;

(f) a droplet analysis subsystem (DAS), having an input orifice for accepting the CDAL that has combined with the charged particles consisting of:

(i) an electrodynamic levitator that levitates the CDAL

that has combined with the charged particles ejected by the PDCS and holds them while the reaction between the CDAL and the analyte occurs,

(ii) a means to control the motion of the particles in the electrodynamic levitator,

(iii) a container that surrounds the levitated CDAL and that is substantially airtight, except for the orifice through which the CDAL enter, so that the CDAL does not evaporate quickly, and so that air currents do not push the CDAL out of the electrodynamic levitator,

(iv) a means to detect changes in the optical property of the levitated CDAL, so that the amount of analyte in the CDAL, and in the particles that combined with the CDAL, can be determined from these measurements of the optical property; and

(v) a receptacle to collect and store the CDAL after the optical property of the CDAL has been measured.

[c2] 2. The APA of claim 1 wherein the optical property is a fluorescence property chosen from a group consisting of the fluorescence intensity, the fluorescence polarization, the fluorescence spectrum, and the fluorescence lifetime.

[c3] 3. The APA of claim 1 wherein the optical property is a light scattering property chosen from a group consisting of the intensity, polarization, spectral intensity, and angular-dependent intensity.

[c4] 4. The APA of claim 1 wherein the analysis liquid is a water solution that contains sensor molecules that selectively bind to the analyte.

[c5] 5. The APA of claim 4 wherein the sensor molecule is protein.

[c6] 6. The APA of claim 4 wherein the sensor molecule is an aptamer.

[c7] 7. The APA of claim 4 wherein the sensor molecule is phage-displayed epitope.

[c8] 8. The APA of claim 4 wherein the sensor molecule is a nucleic acid.

[c9] 9. The APA of claim 1 wherein the charger generates a corona discharge.

[c10] 10. The APA of claim 1 wherein the charger is of the alternating-current corona charging type.

[c11] 11. The APA of claim 1 wherein the electrodynamic levitator of the PDCS is a linear quadupole with a means to control the positions of particles held within the linear quadrupole.

[c12] 12. The APA of claim 1 wherein the electrodynamic levitator of the PDCS is a cubic electrodynamic balance.

[c13] 13. The APA of claim 12, wherein the PDCS further includes a linear quadrupole positioned between the cubic electrodynamic balance and the DAS, and surrounded by at least two rings, so that it can inject the CDAL into the DAS that has a particularly small orifice.

[c14] 14. The APA of claim 1, wherein the charged-droplet input of the PDCS and the charged particle input of the PDCS are identical, because the charged-droplet generator output and the charged particle output of the charger are connected via a gas-tight connection before connecting to the PDCS.

[c15] 15. The APA of claim 1 wherein the electrodynamic levitator of the DAS is a linear quadrupole.

[c16] 16. The APA of claim 1 wherein said DAS further includes a shutter that is open when the CDAL is injected into the DAS, and is closed otherwise, so that the rate that water vapor leaves the DAS through the orifice is reduced, so that the humidity in the DAS remains high.

[c17] 17. The APA of claim 1 wherein said DAS further includes a means to sort the CDAL into different receptacles according to the measured value of the optical property.

[c18] 18. The APA of claim 12 further including a vertically po-

sitioned linear quadrupole, and a substantially airtight tube that surrounds the vertically positioned linear quadrupole and connects to the charged-particle output of the charger and to the CDAL-output of the CDG, and to the input to the PDCS, so that the CDAL and the particles can combine as they are drawn upward through this linear quadrupole and move upward toward the PDCS.

[c19] 19. The APA of claim 11 further including: (i) a vertically positioned linear quadrupole that is bent gradually at the upper end so that at the top of this bent linear quadrupole the particles move almost horizontally, so that the electrodynamic levitator of the PDCS can be a linear quadrupole, and (ii) a substantially airtight tube that surrounds the vertically positioned bent linear quadrupole and connects to the charged-particle output of the charger and to the CDAL-output of the CDG, and to the input to the PDCS, so that the CDAL and the particles can combine as they are drawn upward through this bent linear quadrupole and move upward toward the PDCS.

[c20] 20. The APA of claim 1 further including an aerosol particle concentrator connected to the charger which concentrates the particles before they enter the charger so that the APA is sensitive to particles which contain lower concentrations of analyte and to lower concentrations of

particles that contain the analyte.

[c21] 21. The APA of claim 20 further including a nozzle connected to the output of the aerosol particle concentrator, where said nozzle is positioned inside a sheath-flow tube so that the particles concentrated by the aerosol particle concentrator are kept from dispersing so that a higher fraction of these particles flow past the CDAL so that they can be attracted to the CDAL and combine with it.

[c22] 22. The APA of claim 1 further including an aerosol particle counter to measure the concentration of, and sizes of, particles in the gas so that the numbers and sizes of particles that combine with the CDAL can be determined approximately by using calibration data.

[c23] 23. The APA of claim 1 wherein the analysis liquid further contains an additional sensor molecule that selectively binds to an additional region of the analyte.

[c24] 24.The APA of claim 23 wherein when the additional sensor molecule binds to the additional region of the analyte, the fluorescence of an additional fluorophore changes, and wherein the spectral peak of the fluorescence emission that changes when the sensor molecule binds to the analyte is different from the spectral peak of

the fluorescence emission that changes when the additional sensor molecule binds to the additional region of the analyte.

[c25] 25. The APA of claim 1 wherein the analysis liquid further contains an additional sensor molecule that selectively binds to an additional analyte.

[c26] 26.The APA of claim 25 wherein, when the additional sensor molecule binds to the additional analyte, the fluorescence of an additional fluorophore changes, and wherein the spectral peak of the fluorescence emission that changes when the sensor molecule binds to the analyte is different from the spectral peak of the fluorescence emission that changes when the additional sensor molecule binds to the additional analyte.

[c27] 27. The APA of claim 1 wherein said DAS further includes a means to measure multiple optical properties of one CDAL.

[c28] 28. The APA of claim 1 wherein said DAS further includes a means to measure multiple optical properties of one CDAL.

[c29] 29. The APA of claim 1 wherein said DAS further includes a means to open the container and remove and replace the receptacle, so that the CDAL, or what remains from

the CDAL after the water has evaporated, can be further analyzed.

[c30] 30. The APA of claim 1 wherein said DAS further includes a region in the container to hold water that can evaporate to keep the humidity in the DAS high.

[c31] 31. The APA of claim 30 wherein said DAS further includes a means to detect the water level in the region in the container that holds the water, and a means to inject water into the region in the container that holds the water if this water level drops below some level.

[c32] 32. An aerosol-particle analyzer (APA) for measuring the amount of an analyte in particles in a gas comprising:
(a) an analysis liquid chosen such that when the analysis liquid is mixed with the particles, an optical property of the analysis liquid varies according to the amount of the analyte in the particles;
(b) a charged droplet generator, having a charged-droplet generator output, that generates a charged droplet of the analysis liquid (CDAL) and ejects it out of said charged-droplet generator output when signaled to do so;
(c) a charger, enclosed in a gas-tight enclosure, having a gas input and charged particle output, arranged to:
(i) accept the gas and the particles therein through said

gas input;

(ii) impart an electrical charge to any of said particles accepted, such that the now charged particles will have a charge opposite that of the CDAL; and

(iii) permit the gas containing the charged particles to exit through the charged particle output;

(d) a particle-droplet-collision and analysis subsystem (PDCAS) consisting of a linear quadrupole (LQ) that is positioned vertically and surrounded by an airtight container that has is a charged-droplet input connected to the charged-droplet generator output, a charged particle input connected via gas-tight connection to the charged particle output, a optical-property-measurement subsystem, a receptacle to collect the CDAL after the optical property of the CDAL has been measured, and a vacuum connection that:

(i) accepts the CDAL via the charged-droplet input;

(ii) accepts the gas containing the charged particles via the charged particle input;

(iii) holds the CDAL and particles near the LQ axis as they are drawn upward through the LQ by the flow of the gas, and while the particles flow past the CDAL because the CDAL is heavier, so that the particles can combine with the CDAL so that analyte in the CDAL can be measured; and levitates the CDAL into a position where the gas containing the charged particles drawn from the charger

flows past it so that the charged particles, collide with and combine with the CDAL in part because they are electrically attracted to the oppositely charged CDAL;
(iv) measures the optical property of the CDAL so that the amount of analyte in the particles can be determined; and
(v) collects the CDAL in a receptacle for further analysis after the optical property has been measured; and
(e) a vacuum pump connected to the PDCS vacuum connection that draws the gas and particles into the charger gas input and through the charger and then on into the PDCAS, where the gas and any particles not combined with the CDAL are then evacuated.

[c33] 33. An aerosol-particle analyzer (APA) for measuring the amount of an analyte in particles in a gas comprising:
(a) an analysis liquid chosen such that when the analysis liquid is mixed with the particles, an optical property of the analysis liquid varies according to the amount of the analyte in the particles;
(b) a charged droplet generator, having a charged-droplet generator output, that generates a charged droplet of the analysis liquid (CDAL) and ejects it out of said charged-droplet generator output when signaled to do so;
(c) a charger, enclosed in a gas-tight enclosure, having a

gas input and charged particle output, arranged to:
(i) accept the gas and the particles therein through said gas input;
(ii) impart an electrical charge to any of said particles accepted, such that the now charged particles will have a charge opposite that of the CDAL; and
(iii) permit the gas containing the charged particles to exit through the charged particle output;
(d) a particle-droplet-collision and analysis subsystem (PDCAS) consisting of an electrodynamic levitator, having a charged-droplet input connected to the charged-droplet generator output, a charged particle input connected via gas-tight connection to the charged particle output, an optical-property-measurement subsystem, a receptacle to collect the CDAL after the optical property of the CDAL has been measured, and a vacuum connection that:
(i) accepts the CDAL via the charged-droplet input;
(ii) accepts the gas containing the charged particles via the charged particle input;
(iii) levitates the CDAL into a position where the gas containing the charged particles drawn from the charger flows past it so that the charged particles, collide with and combine with the CDAL in part because they are electrically attracted to the oppositely charged CDAL;
(iv) measures the optical property of the CDAL so that

the amount of analyte in the particles can be determined; and

(v) collects the CDAL in a receptacle for further analysis after the optical property has been measured; and

(e) a vacuum pump connected to the PDCS vacuum connection that draws the gas and particles into the charger gas input and through the charger and then on into the PDCAS, where the gas and any particles not combined with the CDAL are then evacuated.